



LBNE Collaboration PAC Questions

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Fermilab Program Advisory Committee
6/6/13



Artist: Winslow Homer, 1836-1910

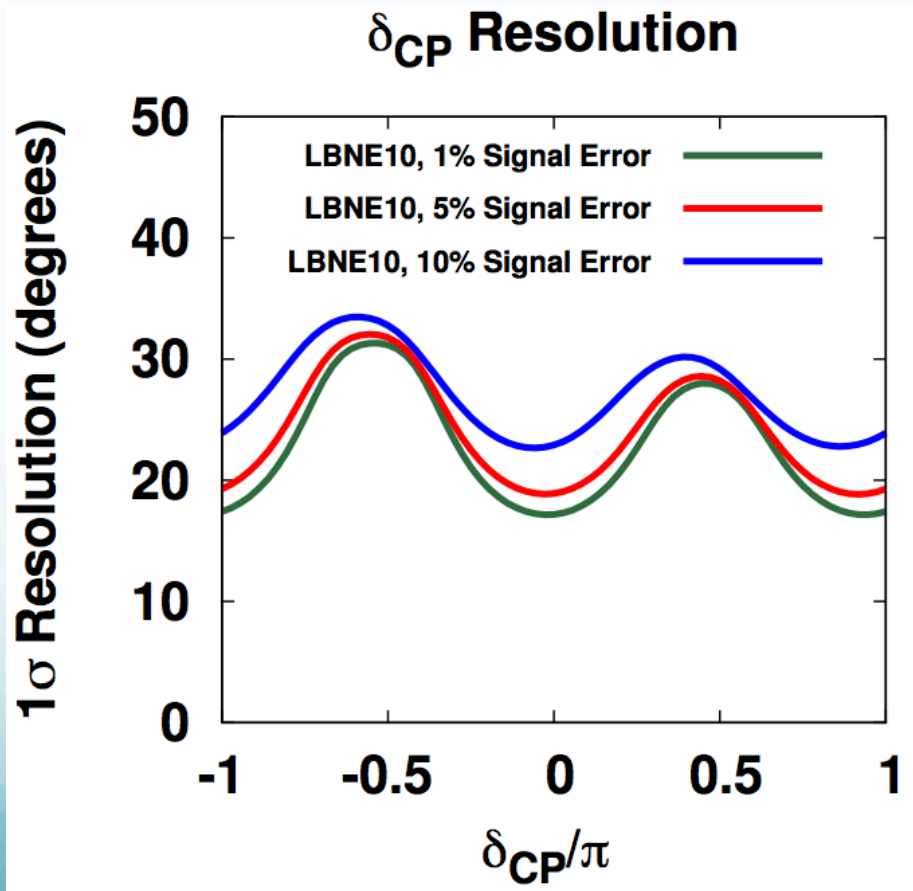


<http://prints.encore-editions.com/500/0/ship-building-gloucester-harbor-drawn-by-winslow-homer-w-h.jpg>

1) With the baseline version of LBNE (no near detector, 10kt on surface) what would be the signal and background normalization systematic uncertainties, based on what is known today? Please show the expected performance (slide 16 in your presentation) under that assumption, and at 5% and 10% systematic uncertainties in the signal.

- With a nominal beam intensity of 700 kW, LBNE with a 10 kt detector expectation is ~ 300 (~ 80) electron (anti) neutrino events for normal mass hierarchy in 5 yrs.
- Past experience from various experiments on systematics is documented in a report to the reconfiguration panel (spring 2012)
- Without a near detector MiniBooNe was able to reduce systematic errors on backgrounds down to 6-7%
- With a near detector MINOS was able to reduce the background systematic error down to 4-5% surpassing the LBNE assumptions.
- Errors on the absolute signal efficiency have been measured using combination of ND and FD data and MC to $\sim 5\%$ by MINOS. Large part of this error is expected to be correlated, and so a careful analysis is needed.
- The extraction of physics from LBNE data will be done with a joint fit to 4 data samples: muon/electron and neutrino/antineutrino with correlated errors on efficiencies. Errors are expected to cancel.

1) With the baseline version of LBNE (no near detector, 10kt on surface) what would be the signal and background normalization systematic uncertainties, based on what is known today? Please show the expected performance (slide 16 in your presentation) under that assumption, and at 5% and 10% systematic uncertainties in the signal.

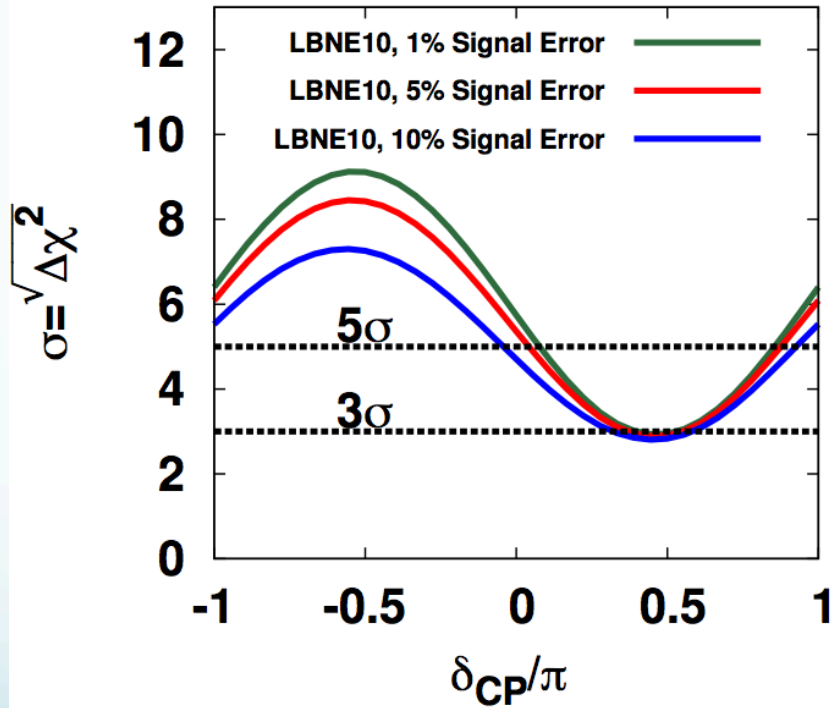


The following plots show the impact on our LBNE10 long-baseline oscillation sensitivities after increasing the uncertainty in the signal normalization from 1% \rightarrow 5% \rightarrow 10%

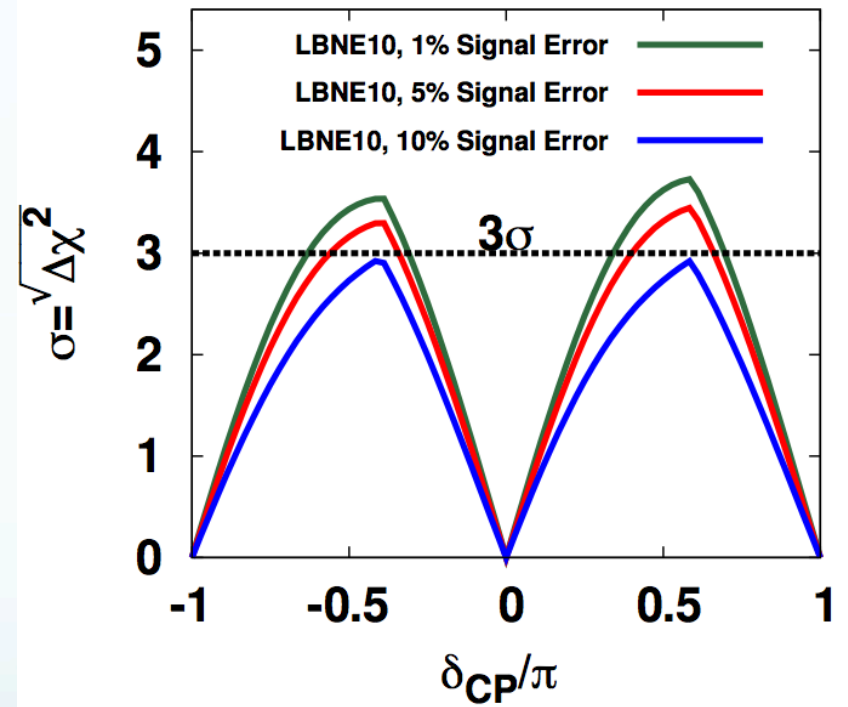
Background error @ 5%

10% error on the signal normalization is very pessimistic

Mass Hierarchy Sensitivity

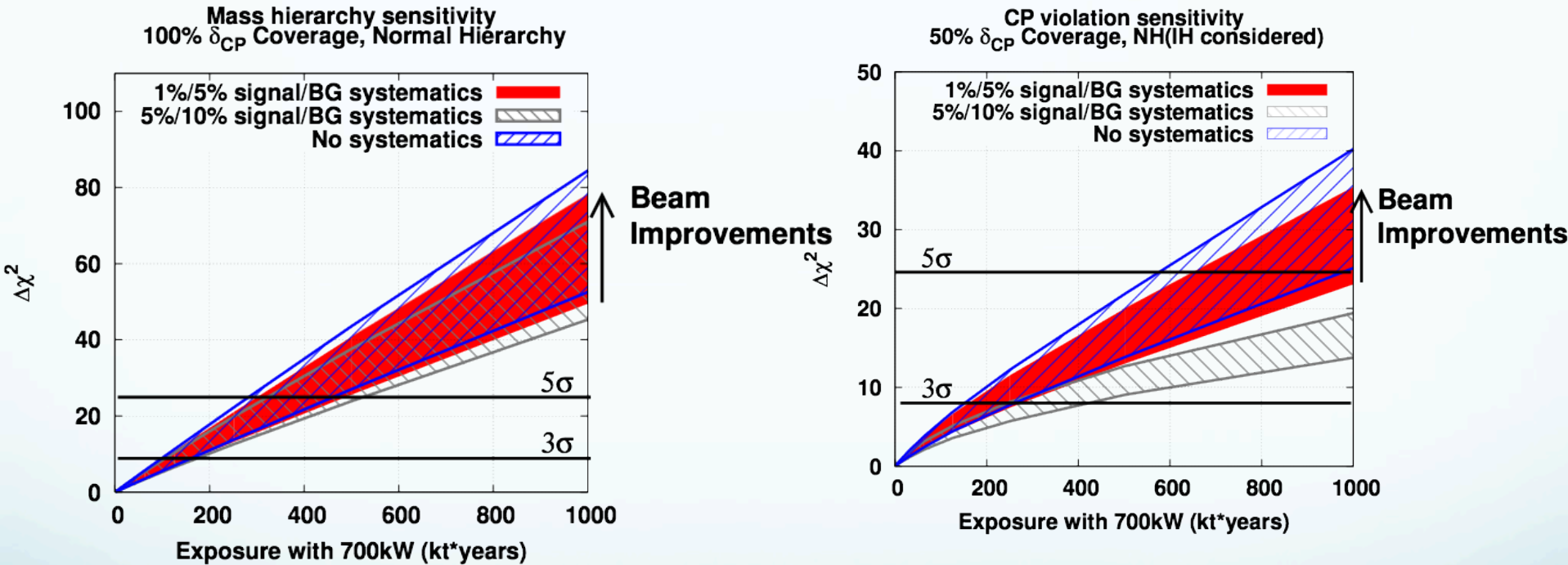


CP Violation Sensitivity



(M. Bass, CSU)

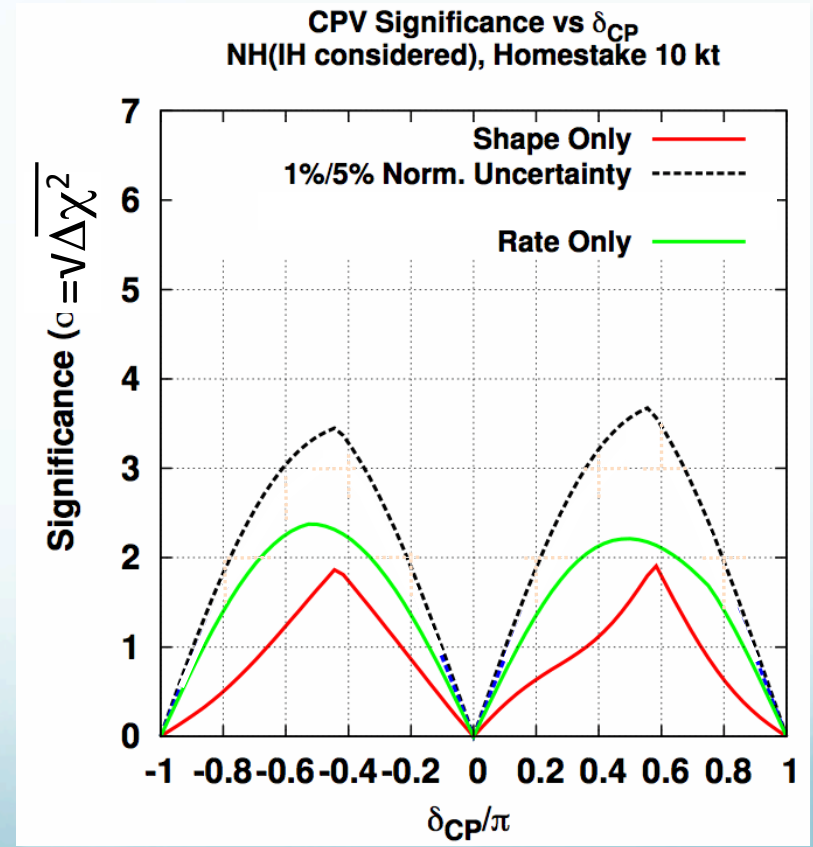
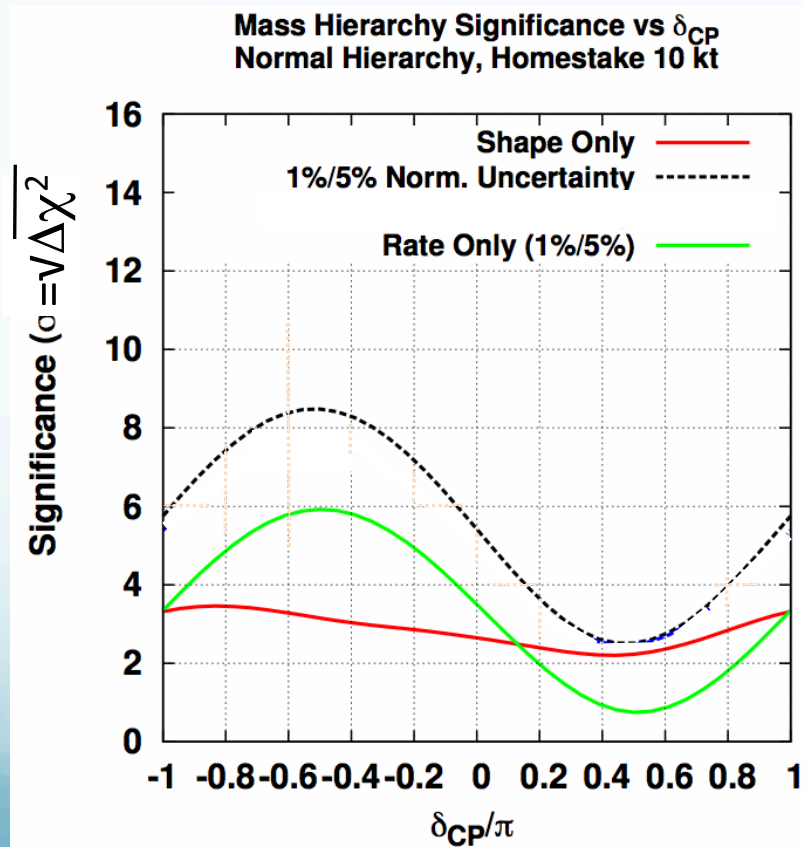
We have also simultaneously varied uncertainties in the background normalization:



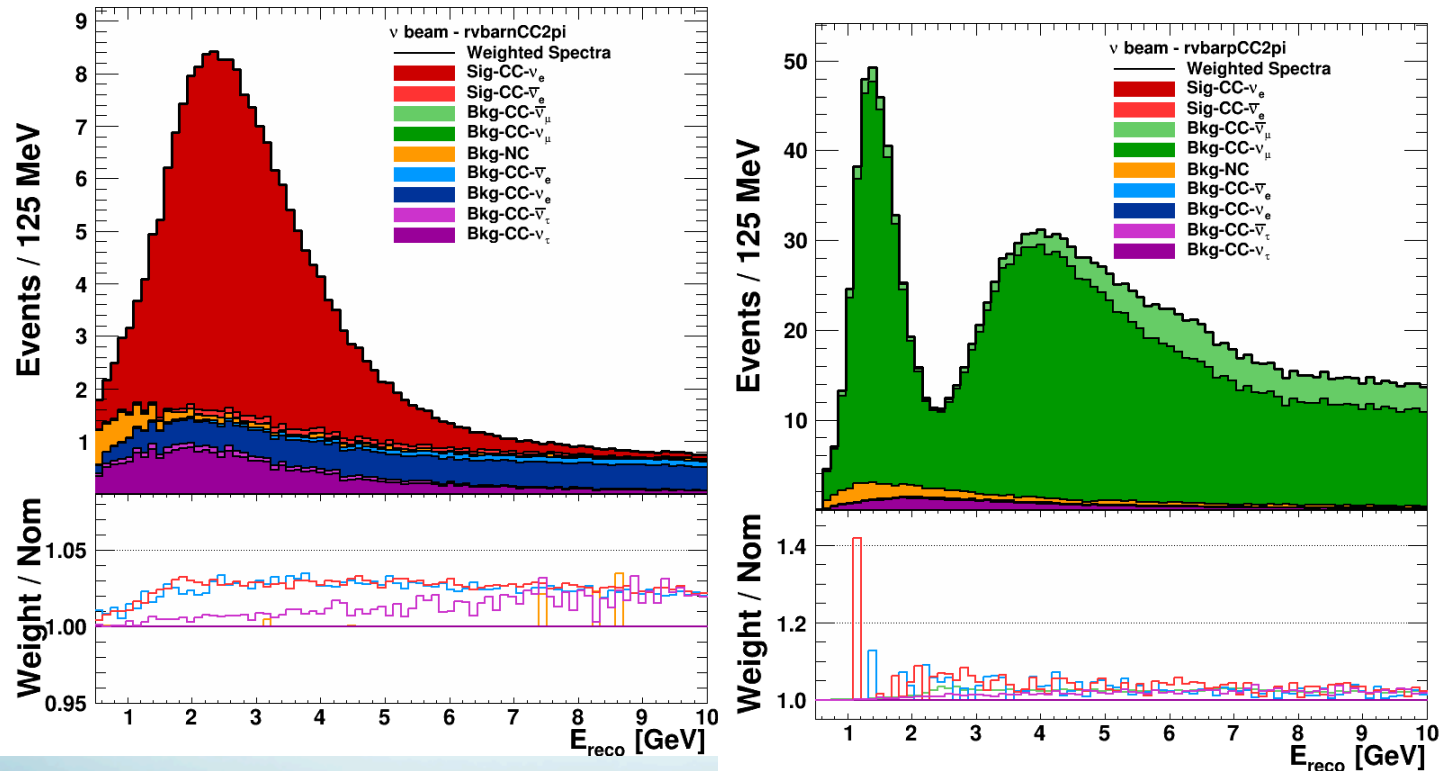
(M. Bass, CSU)

1a) What is the timescale to determine and include uncertainties in the shape of the energy distribution of the reconstructed events for both neutrinos and antineutrinos?

We have studied the role the energy spectra have on our LBNE10 oscillation sensitivities. The shape is particularly important for resolving parameter degeneracies in certain regions (for example, in determining the mass hierarchy for $\delta > 0$).



To investigate shape uncertainties, we have developed a fast Monte Carlo simulation that allows us to vary cross section and flux parameters and use this as input to GLoBES. Below is one such example:



example: varying 2π cross sections in both appearance and disappearance analyses

This is in an advanced state of development.

(D. Cherdack, CSU
R. Gran, UM Duluth)

2) What is the basis of the projection of 1% systematic uncertainty in the signal normalization? What additional measurements worldwide would be required?

Comments:

- LBNE during the initial exposure (LBNE10) is not limited by systematic errors.
- Mass Hierarchy resolution is not limited by systematic errors in majority of the phase space region.
- The precision CPV demonstration and CP phase measurement will require precise control of systematics.
- One of the key reasons for the choice of a high resolution liquid argon TPC was to allow for detailed determination of systematics. MicroBooNe will be very important for this work.

Three handles on systematics: Beam side, near neutrino detector, far detector.

- Based on demonstrated experience with NOMAD, MiniBooNE, and MINOS, the latter two achieved lower than expected systematics, LBNE systematics on the signal/background will be in the range of 1-5%/<5% depending on near detector performance and the elimination of correlations between neutrino/antineutrino data. 1% is the goal.

Near Detector (SST): Absolute and Relative Flux Measurements

Absolute Flux

$\nu_\mu + e \rightarrow \nu_\mu + e \Rightarrow \sim 2\%$ precision in the absolute flux: $0.5 \leq E_\nu \leq 10$ GeV

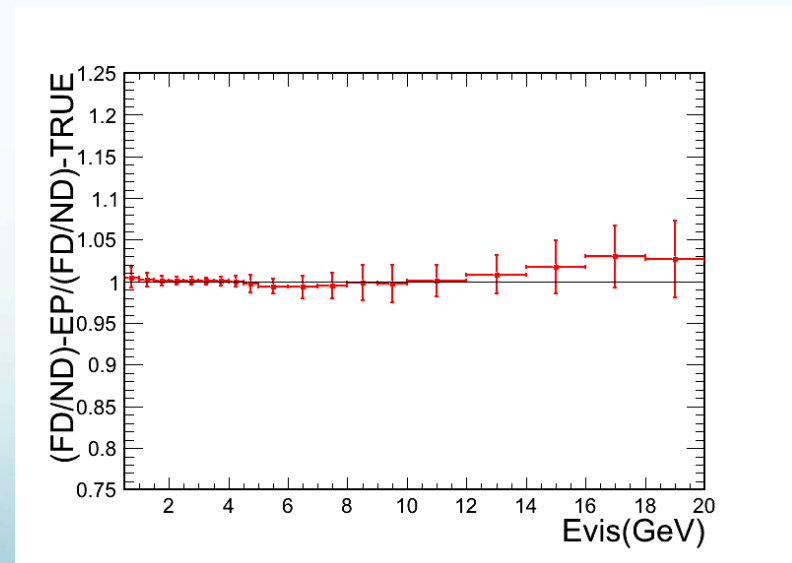
$\bar{\nu}_\mu + p \rightarrow \mu + n \Rightarrow \sim 3\%$ precision in the absolute flux: $0.5 \leq E_\nu \leq 20$ GeV

$\nu_\mu A \rightarrow \mu \rho A \Rightarrow \sim 5\%$ precision in the absolute flux: $2 \leq E_\nu \leq 50$ GeV

(Anti-) ν_μ Disappearance: Relative ν_μ -Flux Measurement by STT using Low- ν_0 technique at LBNE

* Fit the π^+/K^+ cross-section to the ND-'data' with $E_{\text{had}} < \nu_0 (0.5 \text{ GeV})$

* Predict the (FD/ND)



Relative Flux in LBNE

Low- ν_0 Method

$\nu_\mu + N \rightarrow \mu^- + X \Rightarrow$ FD/ND ratio at $\sim 1\text{--}2\%$ precision, bin-by-bin,
in $0.5 \leq E_\nu \leq 50 \text{ GeV}$

$\bar{\nu}_\mu + N \rightarrow \mu^+ + X \Rightarrow$ FD/ND ratio at $\sim 1\text{--}2\%$ precision in $0.5 \leq E_\nu \leq 50 \text{ GeV}$

$\nu_\mu A \rightarrow \mu \pi A \Rightarrow$ a high precision (Expt $< 1\%$; Theory $\sim 1\%$)
in $\nu_\mu/\bar{\nu}_\mu$ in $0.5 \leq E_\nu \leq 50 \text{ GeV}$

Signal: ν_e ($\bar{\nu}_e$) Appearance

- In the LBNE-ND: ν_e ($\bar{\nu}_e$) $\rightarrow e^{-/+}$ is determined via TR & ECAL with $\ll 1\%$ precision;
- ν_μ ($\bar{\nu}_\mu$) $\rightarrow \mu^{-/+}$ is correspondingly measured to a commensurate precision;
- In STT, we will measure the ν_e/ν_μ ratio(E_ν) to $\ll 1\%$ in $0.5 \leq E_\nu \leq 20 \text{ GeV}$ and the $\bar{\nu}_e/\bar{\nu}_\mu$ ratio(E_ν) to $< 1\%$
- Expected ν -Ar statistics is $\sim 50\text{k}$, i.e. Ar-nuclear effects will be measured in situ

So, overall, with $< 1\%$ precision.

2) What is the basis of the projection of 1% systematic uncertainty in the signal normalization? What additional measurements worldwide would be required?

Important input to LBNE systematics

- 1) Target hadron production - accurate prediction of neutrino fluxes and spectra
- 2) Neutrino interaction physics - precise understanding of event topologies as a function of (anti)neutrino energies through the whole energy range important for LBNE
- 3) Detector response - energy resolution and particle ID of hadrons, photons and charged leptons

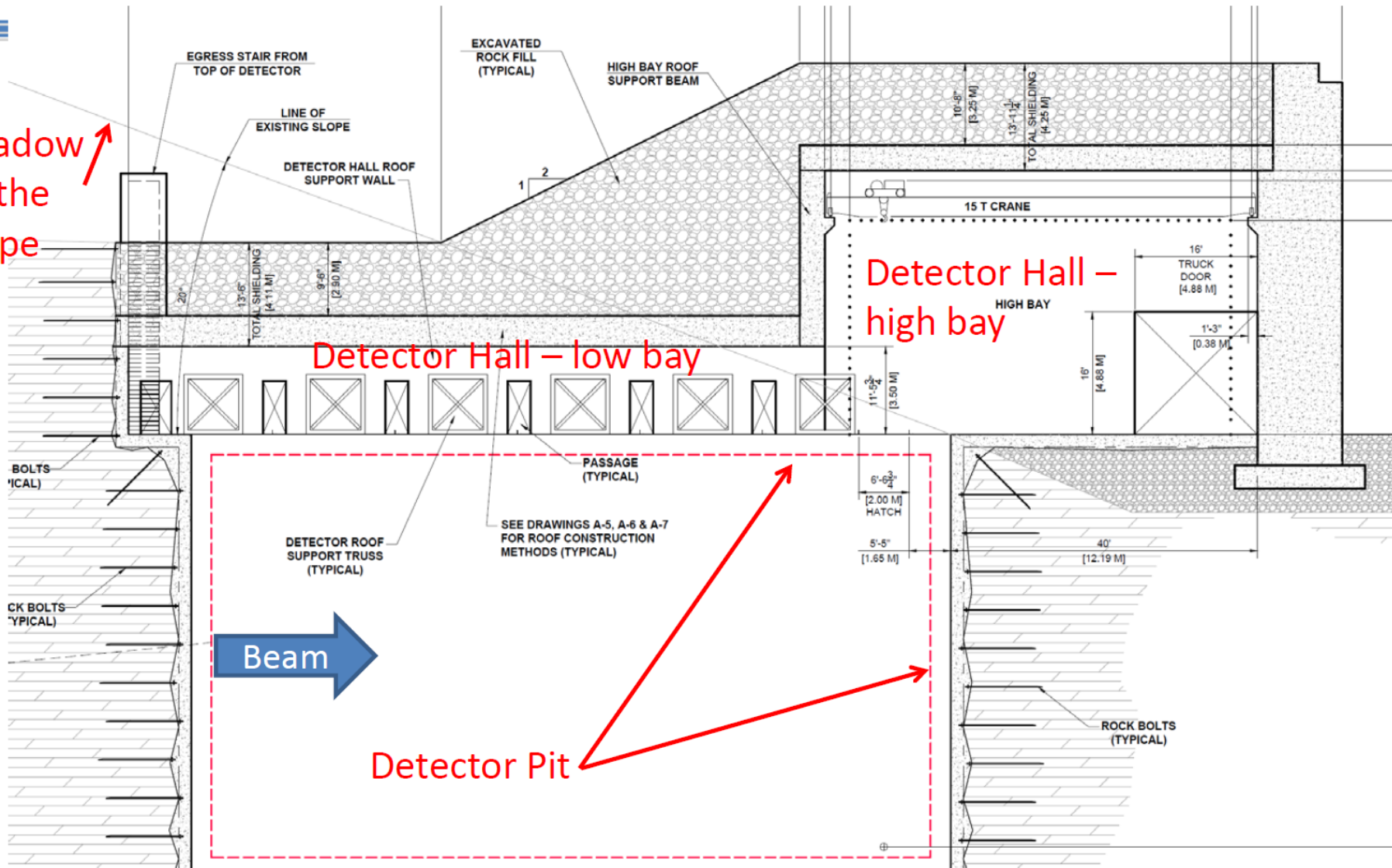
Current and future program of additional measurements and their key contributions to LBNE:

- 1) MINERVA: Cross section measurements and neutrino/antineutrino differences; Nuclear effects in reconstruction.
- 2) MicroBooNE: Cross sections on liquid argon. Nuclear effects due to Argon: Detector effects in reconstruction, e/gamma separation. Booster Nu Beam.
- 3) LArIAT: Track and shower reconstruction efficiency and energy resolution in LAr.
- 4) CAPTAIN: Low energy threshold, Neutron response in LAr. NuMI-ME on-axis.
- 5) MIPP and NA61: hadron production
- 6) LBNO Demonstrator: charged test beam, e/m and hadronic calorimetry, PID, event reconstruction etc. in LAr.

3) What is the current concept for the surface overburden? When will the first 3D track reconstruction algorithms be available for use in the background rejection simulation? What are the requirements on the 3D track reconstruction efficiency to enable the needed background rejection?

- 1m concrete + ≥ 3 m of rock ~ 10 m.w.e. (fig. next slide)
- This rock overburden attenuates the hadronic and soft component of atmospheric cosmic rays by more than 2 orders of magnitude leaving atmospheric muons as the main source of cosmogenic background.
- Muon attenuation is about a factor of 2.
- Positioning detector behind the hill does not help much. Expected reduction in a background rate is 15-30%. Most background events after cuts are found to be caused by energetic hadrons whose directions are not correlated with the direction of an initial muon.
- Accurate surface profile at a potential detector location is being implemented in the Monte Carlo but is unlikely to change the results.

CF FS Reference Design Scope



Details: Conceptual Design Report for the Conventional Facilities at the Far Site:
<http://lbne2-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=5017;filename=CDR-FSCF-volume-final-2012Oct10-reduced.pdf>

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3D track reconstruction efficiency

- Requirements:
 - Accuracy of position reconstruction: better than 2 cm.
 - Energy resolution: 15% at 100 MeV.
 - e/gamma misidentification: no more than 5% of photon showers from neutral pions can be reconstructed as electron-induced showers at 0.25 GeV with a loss of less than 10% of signal events (electron-induced showers).
- Photon detection requirements:
 - Energy depositions at threshold (0.25 GeV) should be located with an accuracy of 2 m or better.
 - Timing resolution of <10 microseconds.

3D Track and Shower Reconstruction Status and Timeline

- 10 kt and 35t simulation is available today and samples of e , μ , π^0 , π^+ , p , and τ have been simulated
- Optical simulation is in progress. A simulation parameterizing photon propagation in 10 kt has been developed and is being checked
- MicroBooNE/ArgoNeuT reconstruction algorithms (such as Kalman Filtering and Fuzzy Clustering) can run on LBNE simulated data,

BUT haven't reconstructed large samples or characterized performance yet because:

- LBNE (Far Detector and 35t) wrapped induction-plane wires create ambiguities in hit interpretation – tracks and showers get split into pieces.

Reconstructed showers would be missing hits and would include stray hits from other activity, such as cosmics, worsening energy resolution.

Track segments degrade our ability to count particles and identify event topology correctly.

Strategies for wrapping differently to eliminate ambiguities under discussion.

Timescale: Tracking and Shower Optical Reconstruction

- Run MicroBooNE reconstruction algorithms with random association of ambiguity choices for induction-plane hits -- we can do this now, but it is not useful for physics
- First-pass disambiguation -- within a month (prototype code exists now)
- Hit Processing improvements – one to two months
- Pattern recognition and reconstruction optimization for increased efficiency and purity -- ongoing project
- Incorporate PANDORA reconstruction:
- Code available, but disambiguation is on the critical path now – few months?
- For optical simulation parameterized simulation runs now for 10 kt. Needs checking; 35t optical simulation also in progress.

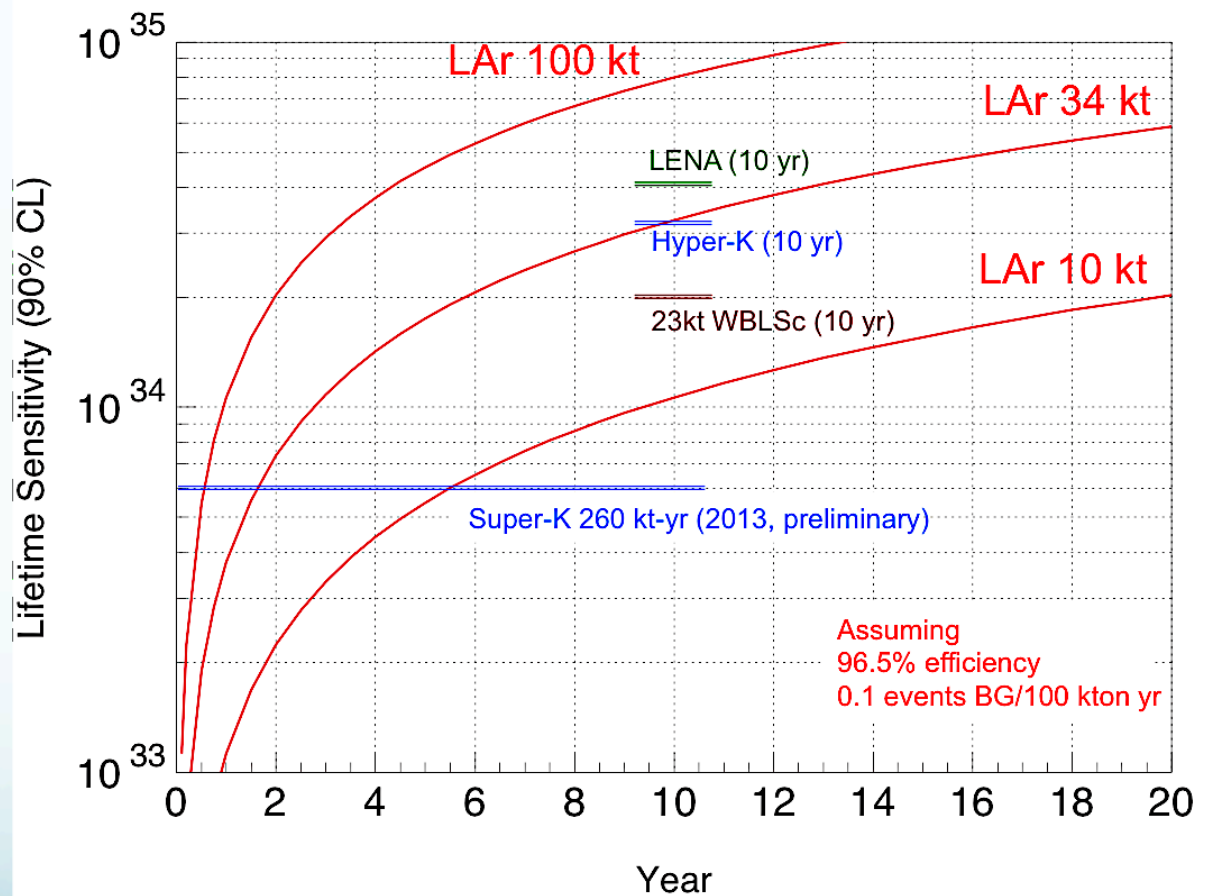
4) Are there potential international partnerships for the accelerator and beam line components of LBNE? If so, how are these being developed?

Potential collaborators on the LBNE neutrino beamline include Rutherford Lab, CERN, Brazil (LNLS), KEK, China (IHEP). Only preliminary discussions have occurred with these, depending on the particular circumstances:

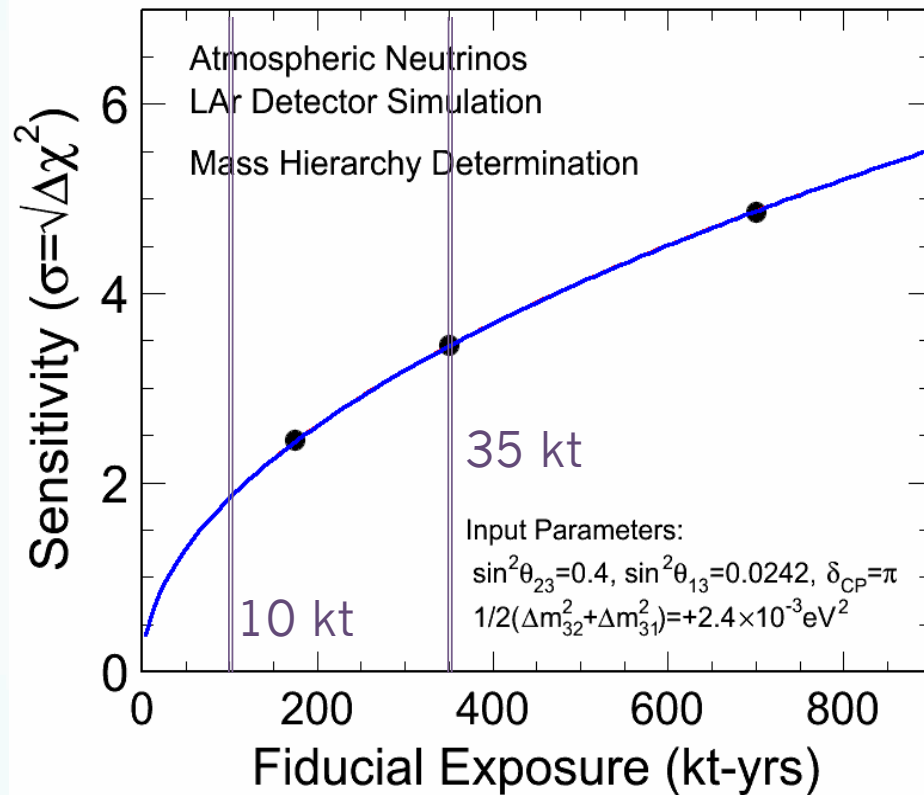
- Accelerator staff at RAL have expressed interest in contributing to LBNE. Further discussions await a broader understanding of the UK role in LBNE, which must be driven by experimental physicists.
- A potential role for CERN in the beamline has been discussed, but further progress depends on CERN's decisions regarding their role in coordinating a European effort on LBNE.
- Contribution of beamline components by Brazil has been discussed in the context of a potential broader collaboration on accelerators, possibly involving their planned new light source Sirius.
- Preliminary discussions with KEK and China suggest that it might be easier for them to contribute to the beamline than to detectors.

5) What is the current understanding of the physics reach for the non-accelerator components of the LBNE program for a 10 kt (fiducial) detector underground? How does this compare with worldwide competition on the same timescale?

Best mode:
 $p \rightarrow \nu K^+$



- Modest improvement over SK
- Factor 3 lower sensitivity than 600 kt (fid.) HyperK concept



Black points at left are sensitivities computed separately for three exposures.

Overlaid in blue is a curve taking the result from the 350 kt-yr run and scaling as $\sqrt{\text{exposure}}$.

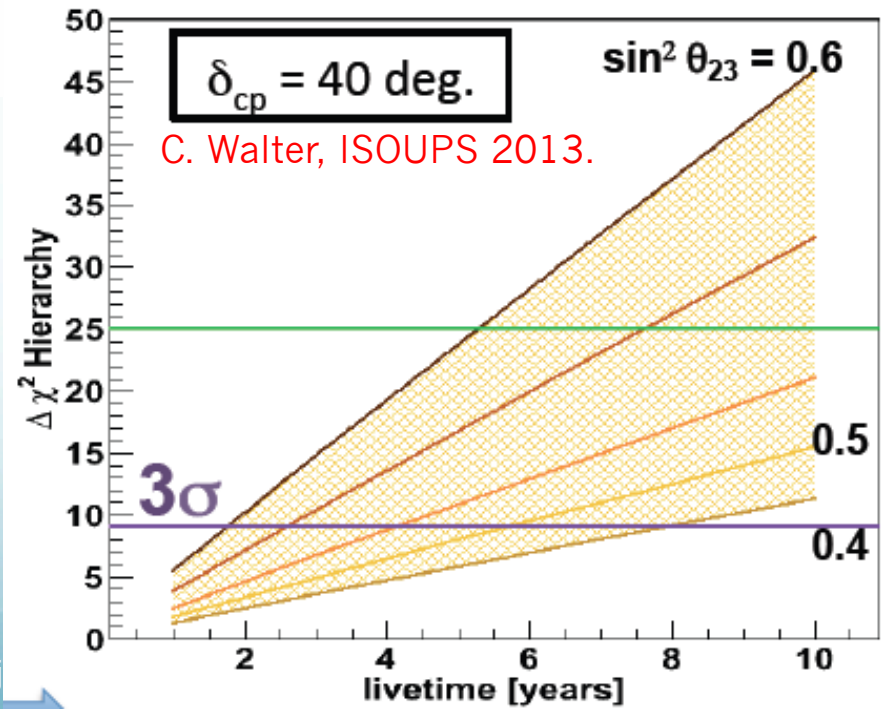
Note: Sensitivity in atmos nu MH analysis is quite insensitive to δ_{CP} value.

HyperK MH Sensitivity

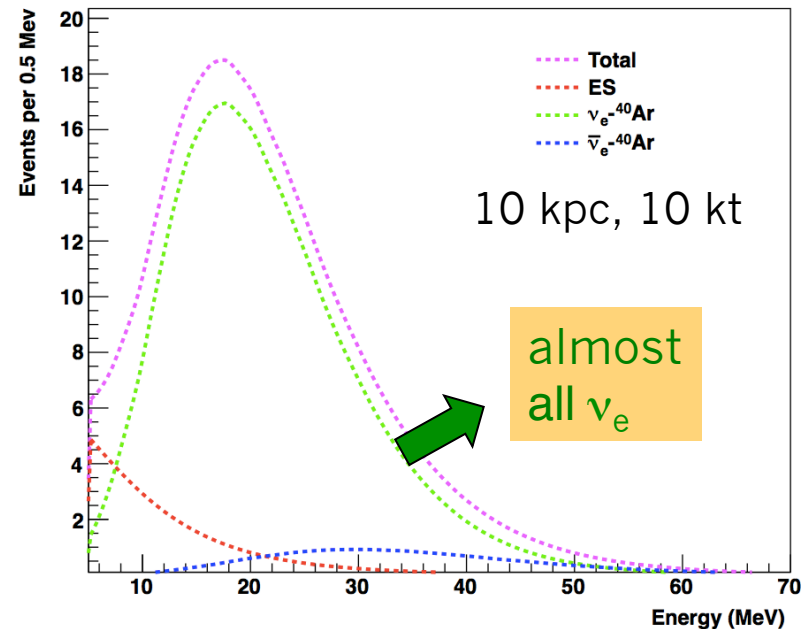
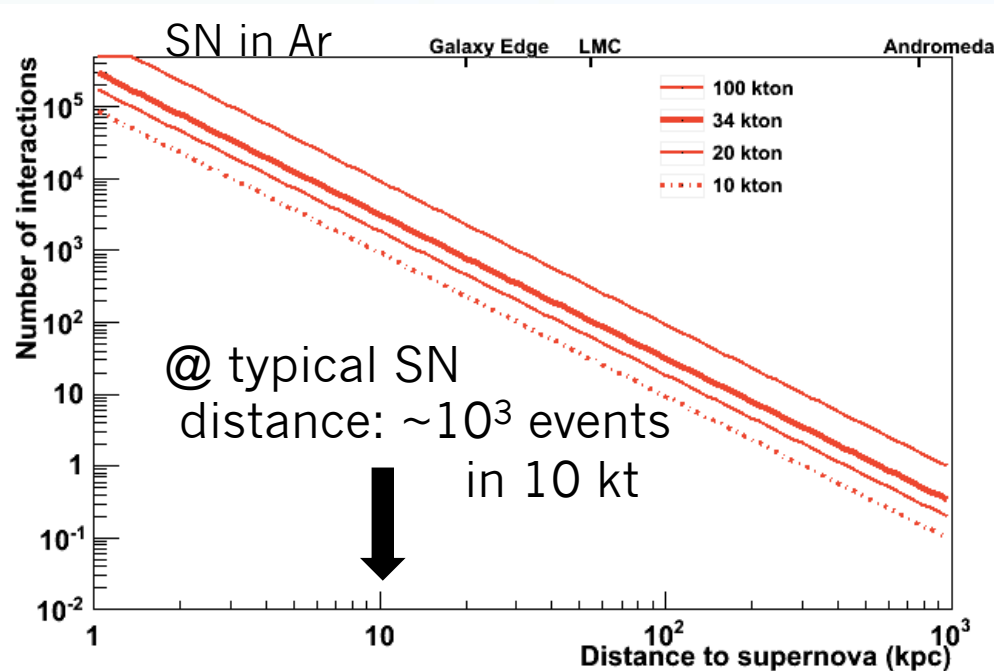
Atmos neutrino MH analyses:

- 10 kt LBNE $< 2\sigma$
- 600 kt HyperK $> 3\sigma$

Combined atmos+beam MH sensitivity in a 10-yr run 2.67σ with 10 kt compared to 5σ with 34 kt.



Supernova Neutrinos with 10 kt underground



Physics (e.g. MH) and astrophysics signatures are rich and varied... many show up in ν_e component

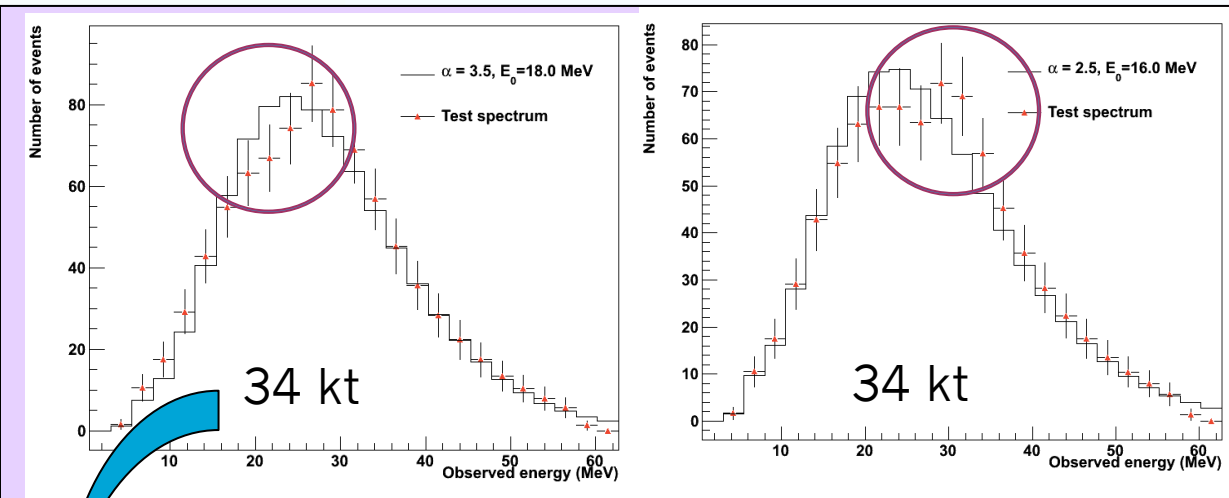
Bigger is always better in this game but

- LAr ν_e sensitivity is highly complementary to water & scint nuebar info
- if there were other LAr programs (none current), detectors separated worldwide can yield info on MSW osc in Earth

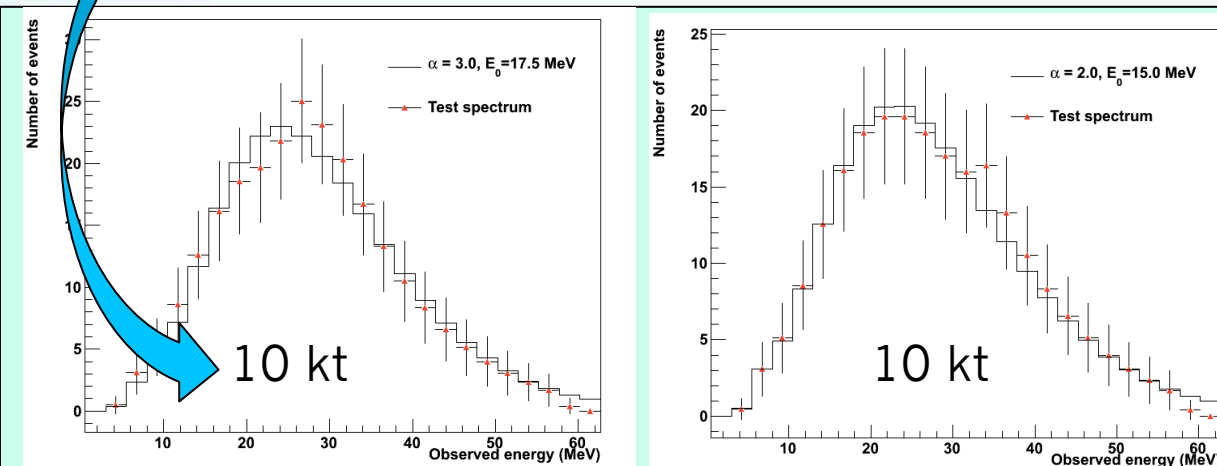
And getting $O(1000)$ SN nu events would be simply fantastic in son many ways!

Snapshots at ~ 1 second intervals (1 s integration) for cooling phase w/ shock, NMH

10 kpc spectra from A. Friedland/JJ Cherry/H. Duan smeared w/ SNOwGLoBES response
Based on Keil, Raffelt, Janka spectra, astro-ph/0208035, w/ collective oscillations + shock
Black line: best fit to pinched thermal spectrum



For NMH (*not* for IMH),
“non-thermal” features
clearly visible,
and change as shock
moves through the SN



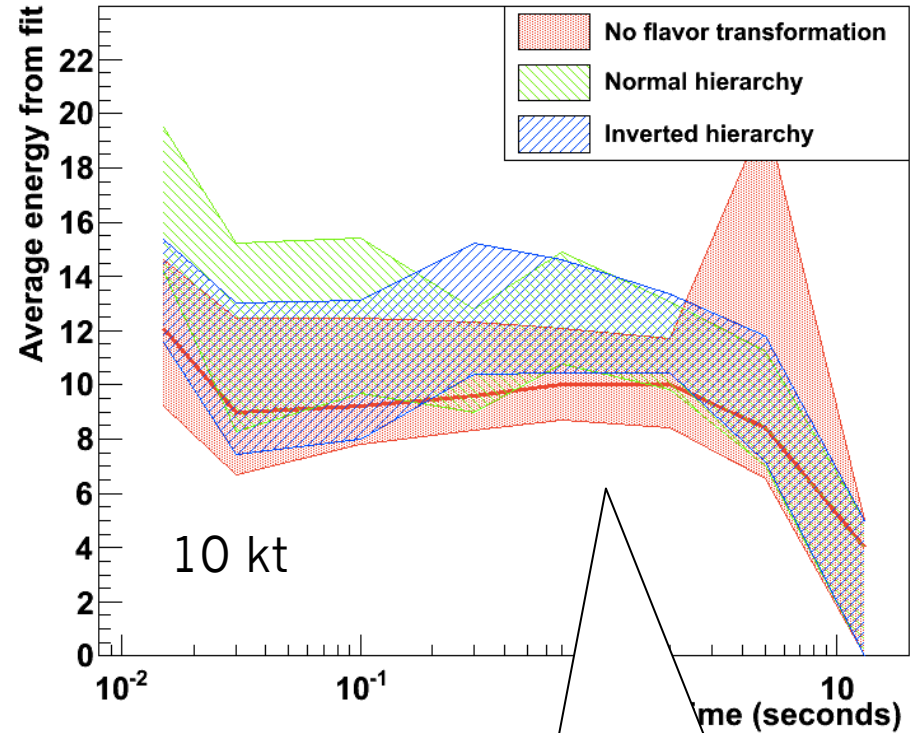
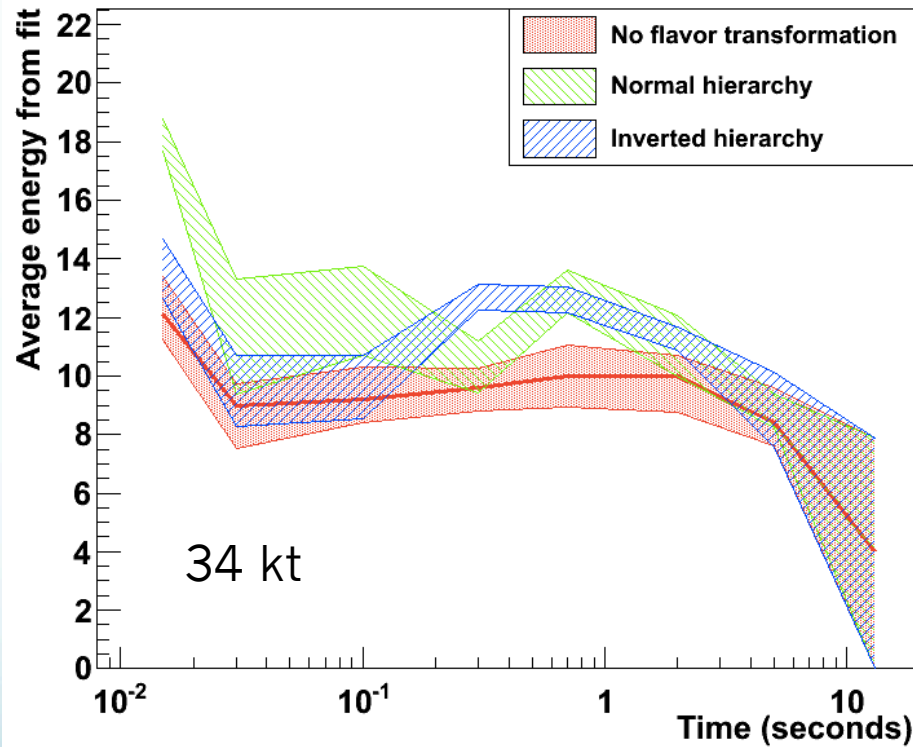
Features become
difficult to see
for 10 kt stats
@ 10 kpc

Measuring SN ν_e temperature vs time

Preliminary: work in progress

10 kpc spectra from A. Friedland/JJ Cherry/H. Duan smeared w/ SNOwGLoBES response, fit to pinched thermal spectrum

Based on Keil, Raffelt, Janka spectra, astro-ph/0208035, w/ collective oscillations (NH & IH)



1σ error bars

Solid line: true $\langle E_\nu \rangle$

10 kt, 10 kpc stats not as good as larger detector but a fit would extract a lot of information